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Cartographic Issues in the Development of a Digital GRASS Database

by
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The process of building a complete and useful database for the Geographic Resources Analysis Support System (GRASS), a geographic information system (GIS), is complex and costly. If data are entered or manipulated incorrectly, the result can be a large, costly body of useless geographic information. The likelihood of such mistakes arises in part from a user's misunderstanding of basic differences between digital map data and conventional analog paper maps. Additionally, a number of environmental planners have been faced with the necessity of creating or editing GRASS databases without substantial training in cartographic concepts or the use of a GIS. This report provides information that will help minimize mistakes commonly made in the creation and modification of GRASS databases.

GRASS is now used widely at military installations, and by numerous other public and private agencies. This report answers some of the questions most frequently asked by GRASS users throughout the public and private sectors. The contents of this report are drawn largely from the collective experience of researchers at the U.S. Army Construction Engineering Research Laboratory (USACERL), where GRASS was developed. Issues addressed include software-specific matters, the characteristics of digital cartographic databases, the relationship between digital and analog maps in general, and the preparation of analog map information for conversion into digital data. (KR)

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13. ABSTRACT (Maximum 200 words)

The process of building a complete and useful database for the Geographic Resources Analysis Support System (GRASS), a geographic information system (GIS), is complex and costly. If data are entered or manipulated incorrectly, the result can be a large, costly body of useless geographic information. The likelihood of such mistakes arises in part from a user's misunderstanding of basic differences between digital map data and conventional analog paper maps. Additionally, a number of environmental planners have been faced with the necessity of creating or editing GRASS databases without substantial training in cartographic concepts or the use of a GIS. This report provides information that will help minimize mistakes commonly made in the creation and modification of GRASS databases.

GRASS is now used widely at military installations, and by numerous other public and private agencies. This report answers some of the questions most frequently asked by GRASS users throughout the public and private sectors. The contents of this report are drawn largely from the collective experience of researchers at the U.S. Army Construction Engineering Research Laboratory (USACERL) GRASS was developed. Issues addressed include software-specific matters, the characteristics of digital cartographic s, the relationship between digital and analog maps in general, and the preparation of analog map information for conversio digital data.Equipment shops in the U.S. Army Directorates of Engineering and Housing (DEHs) normally use written files to air ecords and inventories, and to author reports. This report describes criteria for selection and implementation of co lly available, computer-based vehicle and equipment maintenance management systems that can automate those tasks. Capabilities of appropriate management systems are described, including the use of bar code technology. Two systems (JP Systems' ShopFax, and Prototype's EMS/PC) were selected for test implementation at three Army installation Fort Lee, VA; Fort Riley, KS; and Fort Meade, MD). The report details the experiences of each installation with the introduction of a computer-based management system, and the benefits derived from that introduction. Recommendations are made as to the circumstances under which each system is more suitable.

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FOREWORD

This report was prepared by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (USACERL).

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Dr. Ravinder K. Jain is Chief of USACERL-EN. COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

CONTENTS

FIGURES

TABLES

TABLES (Cont'd)

CARTOGRAPHIC ISSUES IN THE DEVELOPMENT OF A DIGITAL GRASS DATABASE

1 INTRODUCTION

Background

The Geographic Resources Analysis Support System (GRASS) is an image processing and geographic information system (GIS). It is used to manage, analyze, input, and display digital representations of geographic data. Initially developed by the U.S. Army Construction Engineering Research Laboratory (USACERL) for environmental planners at military installations, GRASS is now used in both the public and private sectors to assess environmental impacts, evaluate site suitability, detect change over time, manage resources, and model the effects of environmental phenomena across a landscape.

Building a complete and useful GRASS database is complex and costly. If not done properly, this work can produce a body of expensive, but useless, digital data. Additionally, digital cartographic data often is not well understood by the people who use it. Printed maps have always been an essential tool in environmental planning, but a GRASS digital database is quite different from the maps it will replace. Many of the questions arise concerning the building and understanding of a GRASS database.

Objectives

Three major objectives of this report are:

1. To promote a clearer understanding of GRASS databases among users
2. To provide guidance to GRASS users who need to add map data to an existing database
3. To organize and make readily available at USACERL information on the construction of GRASS databases.

Approach

The information in this report has been drawn from the collective experience of researchers at USACERL involved in the creation and use of GRASS databases, the literature of digital cartography, and the expertise available at USACERL in the areas of cartography and GRASS programming.

2 GRASS CELL MAPS

In GRASS, all analyses are performed on cell maps, one of the basic formats used to present digital catographic data. The user must thoroughly understand how cell maps portray geographic information in order to make appropriate choices about cell resolution and understand the output of GRASS analyses. Some data, however, may be input as vector data; this must be converted to cell format for analysis in GRASS. The user must consider a number of issues relating to the transformation of analog data into a form that GRASS can analyze.

Cell and Vector Data Formats

All GRASS analyses are performed on cell maps, which consist of cells arrayed in a grid pattern, each containing a value to represent a corresponding geographic location (Figure 1). The terms "pixel" and "raster data" are sometimes used to describe this data format. The terms "cell" and "cell map" are used in this document for consistency with other GRASS documentation.

In addition to the cell map format, geographic data may also be stored in a vector format. In this format, the data is stored as arcs, each of which begins and ends with a special point called a *node* (Figure 2).* GRASS uses cell maps in its analyses, but vector maps are used primarily for graphic purposes. Vector analysis is not currently possible in GRASS.

GRASS converts data to cell maps in several ways, depending on the type of data. Geographic data is often classified as an area, a line, or a point. The following sections examine how these types of data are converted to GRASS cell maps. The user is then given general guidelines for choosing the proper resolution for a cell map. Finally, a discussion of conceptual issues in cell data is presented.

Data Formats and Conversion Issues

Much cartographic data is entered into GRASS already in cell format. Examples include satellite imagery, scanned aerial photographs, and elevation data in the form of a digital terrain model.

2	1	3	3	3	3	3	3	1	1	4
2	2	1	1	4	4	4	4	4	1	4
2	2	1	1	4	4	2	4	4	4	4
4	4	1	1	1	1	2	2	4	4	4
4	4	4	4	4	1	4	4	4	4	4
2	4	4	4	4	4	4	4	4	4	4

Figure 1. Cell map.

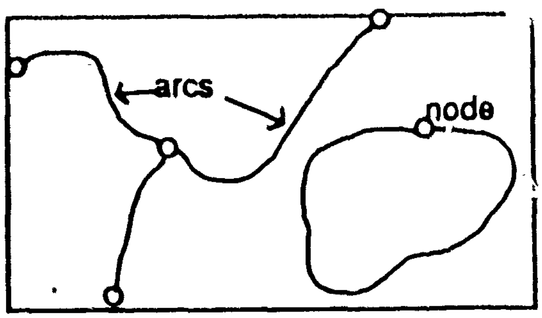


Figure 2. Vector map.

*Other computerized systems dealing with cartographic data may use different terms for describing these concepts.

As previously mentioned, data will also come to the user in a vector format. There are a number of vector formats produced by various systems.

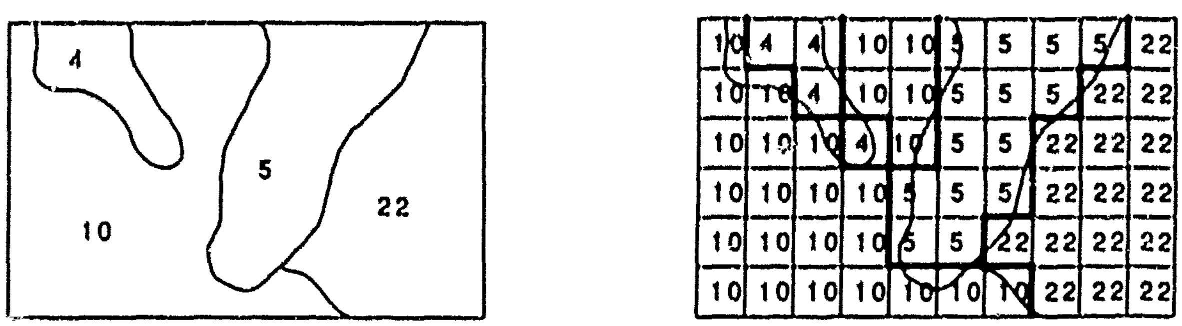
The GRASS 3.1 vector format is known as the *digit* format.[1] For the purposes of this report, vector data is assumed to be in the *digit* format. This may require the user to convert other vector formats to *digit*, or to use GRASS to digitize analog information from printed maps. GRASS 3.1 outputs data in the GRASS *digit* format.

Another important format of GRASS data is called the "sites list." A site is a geographic location where some feature is found; a sites list is a list of coordinate pairs describing the location of several features. The format of a sites list is described in the GRASS User's Reference Manual entry *sites.format(3)*.[2]

To be used in GRASS analyses, vector and sites data must be converted to the appropriate cell format.

Converting Areal Data to Cell Format

Examples of areal data include such themes as classifications of geology, land use, and vegetation cover. The GRASS program *vect.to.cell* is used to make cell maps from vector maps containing areal data. Figure 3a shows a portion of a soils map, with a value in each polygon indicating the type of soil it represents. Figure 3b shows the same information as it would appear in a GRASS cell map. The overlaid grid illustrates how GRASS might divide the map to store it as cells. On a color monitor or printout, the different values in the cells would be represented in different colors. The original polygon boundaries are included in Figure 3b to illustrate that cell values are assigned according to the polygon's value at the *center* of each cell in the overlaid grid.



a. b.

Figure 3. The same area shown as vector and cell data.

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[1] For more information on the *digit* format, see "GRASS 3.0 MAPDEV Vector Format," "GRASS MAPDEV Attribute File Format," and "GRASS MAPDEV Digit File Format" in James Westervelt, Michael Shapiro, William D. Goran, et al., *GRASS User's Reference Manual*, Automatic Data Processing (ADP) Report N-87/22 (USACERL, September 1988).

[2] For more information on sites, see the entries for *sites(1)*, *sites.occur(3)*, *sites.report(3)*, and *sites.S(3)* in James Westervelt, Michael Shapiro, William D. Goran, et al.; and Michael Shapiro, James Westervelt, et al., *GRASS 3.0 Programmer's Manual*, ADP Report N-89/14 (USACERL, September 1989).

Converting Linear Data to Cell Format

Linear map data includes such themes as roads or streams. Because GRASS performs analyses only on cell data, lines must often be converted to cell maps. Linear data starts as a vector file, and is converted with the GRASS program *vect.to.cell*, just as areal data is. The Bresenham algorithm, which converts linear data into cell format, is different, however, from the one used to convert areal data. It creates a cell map in much the same way a line is displayed using the pixels of a color graphics monitor. The algorithm makes decisions about the representation of the line based on which cells will most closely represent the original line (Figure 4). As a result, some cells that actually contain a part of a line will not be activated if that would distort the essence of the line. This algorithm is not perfect, but it gives a better rendition of linear data than would the center point plotting method used for areal data.

Converting Pointal Data to Cell Format

Archaeological sites, helicopter pads, and windmills are examples of pointal data. Pointal data is converted to cell format by the GRASS *sites* program.

The *sites* program allows the user to choose one of two methods by which points are converted to cell format. One method is based on a simple binary presence/absence concept. Empty cells are assigned a value of 0. Any other value indicates that a site is present. Figure 5a represents the location of sites in the original sites list. Figure 5b illustrates the presence/absence concept. The value is assumed to be 1 unless a pound symbol (#) is placed before the description number in the sites list file, which indicates that the site number should be used as the cell value. The other method of converting pointal data to cell format assigns values that indicate the *number* of sites located in a cell. A cell without a site would get a value of 0, a cell with one site would get a value of 1, two sites would be represented as a 2, and so on (Figure 5c).

Choosing the Correct Cell Resolution

Choosing the resolution of a cell map can be a complex process. First, and most importantly, the user must understand exactly what is meant by cell resolution. Then, when a new cell map is created, a number of conceptual and practical issues must be addressed.

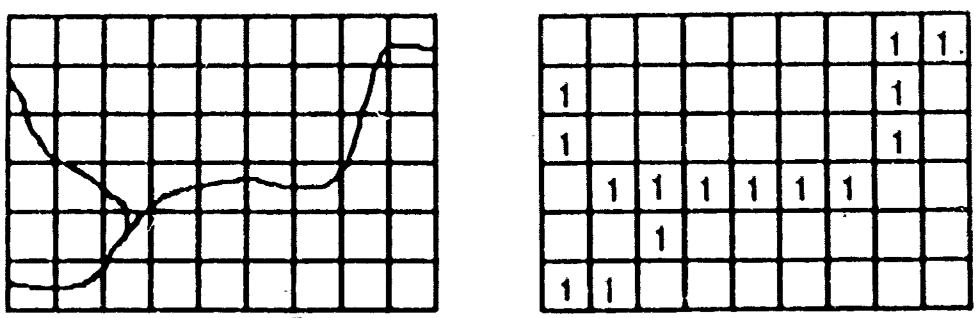

Figure 4. Converting linear data to cell format.

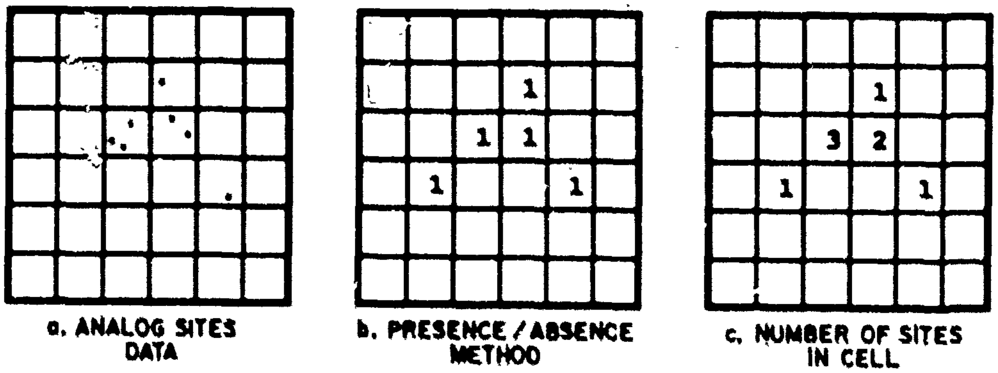

Figure 5. Two ways to represent sites in cell format.

General Issues in Cell Resolution

When the resolution of a cell is measured in meters, the number of meters specified on the GRASS window statement indicates how many meters one side of a cell will represent. A low-resolution map might use a cell to represent 100 meters or more. A high-resolution map may use a cell to represent about 10 meters per side. Essentially, the level of resolution determines the area of the piece of the earth to be represented by one cell.

The GRASS user selects the desired resolution before creating a new map. This is done by designating the desired resolution for the current GRASS window. In most cases, the resolution of the current window dictates the resolution of the cell map. (An exception to this is the program *slope.aspect*, which uses the resolution of the original elevation file to set the resolution of new cell files regardless of the current window setting.) Unless the user actively changes the resolution, it retains its value from the previous session. The current window resolution may equal the default resolution, but it may also be set unusually low because somebody wanted to see a rough view of a cell map. The user must always be aware of the current window settings before creating a new cell map.

Once the resolution of a new cell map is set, the geographic detail available in that map is fixed. The user may subsequently use the GRASS *window* command to change the working resolution of a cell map, but the original resolution remains intact. Increasing the resolution of an existing cell file will only subdivide the information from the existing cells. It is important to understand that increasing the resolution of an existing cell map cannot actually access more data than was originally present.

Conceptual Issues in Cell Resolution

When creating a new GRASS cell map, some data may already be in cell format, and some may come from printed maps. Each kind of data must be treated differently.

The two most important examples of data existing in cell format are satellite images and digital terrain models. The resolution of these types of data is generally dictated by their original resolution. In satellite imagery, the original resolution is the result of that satellite's technical limitations. In digital terrain models, the original resolution is based on the scale of the source material and the sampling density of the points taken from that source.[3] Outside of resampling to limit the size of the final cell map, little is gained by changing the original resolution on the finished GRASS cell map.

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[3] See Stuart Bradshaw and Pam Thompson, *Options for Acquiring Elevation Data*, Technical Manuscript (TM) N-89/20 ADA220934 (USACERL, January 1988), for a description of some standard digital elevation model (DEM) products.

The choice of cell resolution is not clear cut in the case of data from analog maps. There are at least two ways to decide, but the user must determine which alternative is best.

First, the user might use the map's scale and overall quality to determine the appropriate resolution. Large-scale maps may be accurately represented by relatively high-resolution cell maps; small-scale maps should be represented by relatively low-resolution cell maps. (See the section entitled **Map Scale** in Chapter 4 for a discussion of map scale.)

Table 1 may be used as a general guideline for considering map scale. The resolutions suggested in the table are based on the assumption that a printed map of moderate scale may be resolved to a level of between 0.75 mm and 1.5 mm. That is, an area of about one square millimeter, as measured on a printed map, would be included as a single cell in a cell map. These measurements are not fixed, but they have been determined partially by experience. Also, it has been said that quality American maps are accurate to about 1 millimeter.[4]

The table values were determined as follows. If, for example, the scale of a map is 1:24,000, a distance of 0.75 mm (the lower end of the resolution range suggested above) would represent 18 meters (0.75 mm X 24,000 = 18,000 mm). The value of 18 meters is rounded up to 20 for use in the table. Therefore, the cell resolution of a better-than-average digital representation of a 1:24,000 map would be 20 meters.

Using the guidelines from Table 1, the resultant cell maps would be more or less "chunky" depending on the scale and quality of the source map. It can be argued that this roughness might be a fairer representation of the feature being depicted than would a smoother one. In the case of ambiguous boundaries, such as those on a soils map, the rough cell version may actually be conceptually more accurate than a smooth line.

The user's other option is to follow the original map as closely as possible by choosing a high-resolution cell grid. It can be argued that this option is better because there may be no good reason to add ambiguity to an already imperfect representation. The scale of the map would thus be a factor primarily in a map-user's assessment of the data's value for a particular application.

Although these two methods of setting cell map resolution are conceptually different, in practice the final result is often similar. However, a smaller scale map is more likely to be represented at a higher resolution by the second method than the first.

Practical Issues in Cell Resolution

Several other practical considerations affect cell resolution decisions. One is that GRASS cell files can be quite large, and the higher the resolution, the larger the file will be. The user may find that a dataset large enough to reach the limits of the computer's memory and disk storage may be cumbersome to use. GRASS can compress cell maps, however, to take up less computer space. Once compressed, high-resolution cell maps with a lot of "empty" space (e.g., linear themes) will take up little more space than they do at a lower resolution.

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[4] Andrew M. Glusic, *The Positional Accuracy of Maps*, Technical Report (TR) No. 35 (U.S. Army Map Service [AMS], Washington, D.C., 1961), p 15.

Table 1

Suggested Range of Resolutions for Common Map Scales

Map Scale	Resolution Range
1:15,840	10-25 meters
1:20,000	15-30 meters
1:24,000	20-35 meters
1:31,680	25-50 meters
1:50,000	40-75 meters
1:63,360	50-95 meters
1:75,000	55-110 meters
1:100,000	75-150 meters

Another practical consideration is that all maps used in a single analysis must be read at the same cell resolution. Many analyses may require either satellite imagery, a digital terrain model, or both. As discussed above, data from these types of maps is best used at its original resolution. In such cases, data from printed maps should probably be made to match the resolution of the satellite image or terrain model used in the same analysis. The resolution of satellite images and terrain models tends to range from 20 to 30 meters, so this is often the practical limit of resolution at which any layer of map data should be set. (A map layer is a set of cartographic data representing common geographic features found within a map's boundaries.)

Sometimes the designation of a lower resolution is useful to give a quicker (but rougher) view when displaying or printing a map layer. The user should be aware that using a lower resolution may cause certain features—particularly small polygons and horizontal or vertical lines—to disappear.

In certain cases it may be desirable to represent linear themes and sites by a resolution that reflects the true measure of the feature's width. A road that is about 10 meters wide, for example, could be represented by cells at a resolution of 10 meters. Sites may be converted to cells at a resolution that reflects the average measure of the sites involved, if they are all about the same size. Another approach would be to set cell resolution to equal a standard unit of measure—1m, for example. This approach would be helpful for estimating linear distances. Because, in this example, the cell size would represent one square meter, the area given for the road or stream (as listed on a report of areas) would provide a good approximation of the feature's length.

When converting sites data to cell format the user should be aware of how the choice of resolution and method of representing the data will affect the character of the resultant cell file. Using the presence/absence method of representing sites, a lower resolution might cause two sites to fall within the same cell, and consequently they would be counted as one. On the other hand, using the sites-in-cell method, a lower resolution would cause the grouping of two (or more) sites in one cell, but its value would actually reflect the number of sites present. The user must choose the method and resolution most appropriate for a particular analysis.

3 DIGITIZING MAPS FOR A GRASS DATABASE

Getting Started

Before any cartographic data is actually digitized, preparation of the database is required. The user must also decide whether the digitizing will be done manually or by an electronic scanning device.

Creating a Database

A database is a collection of map layers containing various geographic themes for a given location. At USACERL, databases have been developed primarily for environmental offices at military installations. These maps help military environmentalists make decisions about land management.

When creating a database, several issues must be resolved. First, it must be decided which map layers will be needed in the database. In general, the choice of layers depends on the location for which the database is being developed. In the case of databases created for military environmental offices, it depends on the duties of the environmental office at the installation. A list is made of all map layers that would be useful for the environmentalist's applications. Second, the GRASS data developer must determine how much of this information is available in digital or nondigital format.[5] If the information is not available, the user must consider the practicality of creating the map layer. Finally, the user must decide how many layers will be created, and in how much detail. These decisions must be based on the purposes for which the layer is to be used. For example, if the environmentalist wants to know where roads on the installation are located, but is not concerned with what *types* of roads are there, all roads would be put into a single layer called "roads." If, however, the environmentalist needs to know whether the roads are primary, secondary, or trails, a separate category would be developed for each type.[6]

Manual Digitizing vs. Scanning

When it has been determined which nondigital map data will be added to a database, and how detailed the categorization of the data will be, decisions must be made about how to convert the data into digital form. Either a manual digitizing device or an automatic electronic scanner may be used to convert analog data into digital form. The manual digitizing unit is a computer input device consisting of a table and a cursor. This cursor, also called a "puck," somewhat resembles the well known computer "mouse." However, the resemblance is superficial; the operator uses the cursor's crosshairs and specialized input keys to trace features from an analog map and convert them into digital data. Any labeling of traced features must be done manually.[7] The automatic electronic scanner converts the line information into digital format by scanning the map and recording locations where it reads black lines. As with the manual digitizer, labeling must be done by hand.

Several factors determine whether a map will be manually digitized or scanned. Generally, a map will be manually digitized if it contains a low density of geographic features. Also, manual digitizing may

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[5] For sources of digital data, see Mark D. Johnson and William D. Goran, *Sources of Digital Spatial Data for Geographic Information Systems*, Technical Report (TR) N-88/01/ADA189788 (USACERL, December 1987); for sources of nondigital data, see William D. Goran and R.E. Riggins, *Geographic Materials to Support Biophysical Quantitative Environmental Impact Analysis--Sources of Existing Materials*, TR N-68/ADA069097 (USACERL, March 1979).

[6] For more information about the creation of a GRASS database, including charts of possible map layers and applications, see Mary V. Martin et al., *GRASS/GIS Implementation Guide*, Special Report (SR) N-90/02 ADA214623 (USACERL, October 1989).

[7] For a complete description of the manual digitizing process, see the GRASS tutorial "digit; Its Use and Its Features" in James Westervelt, Michael Shapiro, William D. Goran, et al.

be required when the project deadline does not permit a scanning contract to be awarded and computer time is available on the digitizing unit.

A map will usually be scanned if there is a high density of geographic features to be recorded and there is enough time to award a scanning contract, or there is no manual digitizing unit available at the site. These are only general guidelines, so special circumstances may require different approaches.

Preparing an Analog Map for Digitizing

Manual digitizing is not usually done directly from a paper map. The following steps may be necessary before digitizing a map by either method.

The Need for Redrafting

In many cases a map's features must be redrafted before the map can be digitized or scanned. When a map is to be scanned, the main technical reason for redrafting is that many electronic scanners can read only solid black lines. On most printed maps, features are represented by different colors, line weights, or line patterns that a scanner cannot interpret. For U.S. Geological Survey (USGS) topographic maps, it is possible to purchase an overlay (called a map separate) that shows a single geographic theme in black ink. In many cases, however, the separate will not be in a ready-to-scan format. For example, unwanted linear or areal data may be included. When redrafting the features onto an overlay, the goal is a clean, uncluttered map showing only one geographic theme. (As scanning technology improves, however, this limitation is becoming less important.)

Another reason for redrafting is the opportunity it provides to compile map information from different sources onto a single overlay, thus requiring that only one mylar overlay need digitizing. During the redrafting stage, decisions about the project area can be made. For example, if a database is being created for an installation, the drafter must decide whether data is to be taken only from within the installation boundaries, or up to a certain distance beyond the boundaries. Decisions about how the features will be categorized can also be made at the time of redrafting. When aligning two adjoining source maps, any discrepancies where they connect can be corrected. Finally, because any map is likely to contain errors, the user must make sure that corrections are made so they will not be required during the digitizing process.[8]

Initial Documentation

During the initial stages of a project, certain information should be recorded for later use during map preparation. The data developer should first list all source maps and documents provided for the project, and who provided them. For maps, this list should include the map's name (e.g., watershed map, streams map, etc.), scale, Universal Transverse Mercator (UTM) zone, source (e.g., USGS, Defense Mapping Agency [DMA]), date, and other information of importance (Figure 6). If other documentation is provided, the user should record its title, date, author, and briefly summarize its contents.

Next, record the geographic feature categories represented on the map, and the source from which the categories were taken. Each category must then be given an attribute code number. To assign these codes, list all data categories, beginning with "no data." Then number each category, with zero representing "no data." Make sure the codes are consecutive numbers (Figure 7).

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[8]Fleet, Harvey, Chief, Branch of Digital Cartography, U.S. Department of the Interior National Park Service (unpublished interview, 29 May 1990).

Roads Map
1:24,000
UTM zone 13
Source map from USGS topographic map Deadwood, 1982
(Information taken from a mylar separate rather than a paper map)

Soils Map
1:24,000
Source: from SCS Soils Survey for Lawrence County, 1976
(Flat soils sheets were not available)

Figure 6. Map information.

Road Categories (using USGS road classifications)	Soil Categories (using SCS soils classifications)
0 no data	0 no data
1 primary highway	1 AaB
2 secondary highway	2 Ba
3 light duty road	3 Bb
4 unimproved road	4 BcA
5 trail	5 BcB

Figure 7. Category information for geographic features.

Map and Mylar Layout

After the initial work is complete, use drafting tape to secure the source map on a table, with the frosted side facing up if the source map is on mylar. It is important to tape down the map as smoothly as possible to avoid distortions while drafting. (Appendix A lists materials necessary for the map preparation steps described here.) Next, cut a rectangular piece of mylar that will cover the project area and its reference points. (For more information about reference points and registration marks, see the section *Map Registration* later in this chapter.) If the map is to be electronically scanned, make sure there is enough room on the mylar, beyond a corner registration mark to record the legend information. Tape the overlay to the table and gently clean it with rubber cement remover or alcohol on a soft cloth.

The UTM reference points are drafted on the overlay first. Using a 0 or 00 technical pen, trace the registration marks from the map onto the mylar. Assign a unique number or letter to each reference point. Then, in a corner of the mylar, record the following information: (1) title of the map project, (2) name, date, scale, UTM zone, and source of the map, (3) the mapmaker's name and the date, (4) the Northing and Easting coordinates for each of the reference points, and (5) any other important information. If multiple sheets are needed to complete the overlay, use the bottom of each sheet to sketch the relationship of that sheet to the entire project area (as in Figure 8).

Soils Map
U.S.G.S Spearfish quad
1:24,000, 1982
UTM Zone 13
Messersmith - April 1988

Reference Points:

	N	E
(1)	4515000	760000
(2)	4499000	760000
(3)	4515000	772000
(4)	4499000	772000

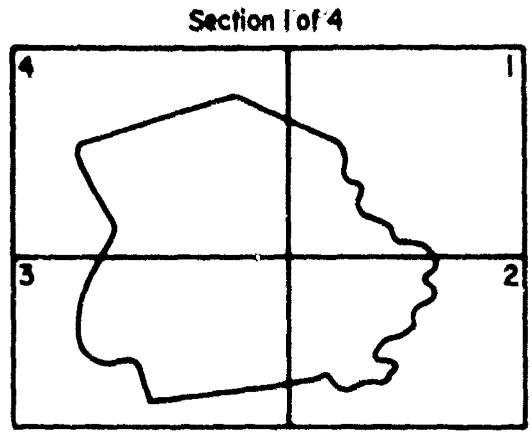


Figure 8. Map information on overlay.

Drafting the Lines

The technical pen is used to carefully trace map features onto the overlay. If a line is not drawn properly, it can be erased with the gentle rub of a moistened pen eraser. Excessive eraser pressure, however, may remove the mylar's frosted coating, rendering that portion of the surface unsuitable for further drafting. A razor blade or knife can also be used to correct lines, but these, too can damage the mylar. These tools are best used to touch up lines that will not be redrafted.

Assigning Attribute Codes

Cut a second sheet of mylar to approximately the same dimensions as the first sheet, and tape it over the completed overlay. This top overlay is for coding the attributes recorded in the first overlay. Using the technical pen, trace the UTM intersections from the four corners of the completed overlay onto the new mylar. Label these intersections with their respective coordinates; they will be used to align the two overlays. Then assign each feature on the map its proper attribute code from the list completed earlier. If the feature being labeled is a line, write the code *on* the line. If, however, the feature being labeled is an area, write the code *inside* the polygon (as shown in Figure 9).

Editing

The final stage of map preparation involves editing the feature and attribute code overlays. Although this stage can be tedious, it is necessary to ensure accuracy. It is often helpful to establish a large grid system on a sheet of clear acetate, and place it on the mylar overlay for use as an editing guide. For editing a complex overlay, the best approach is to first align and affix the feature overlay atop the source map, and place the acetate grid on top of everything. Editing section by section, make sure every line has been drafted correctly. Next, remove the feature overlay and secure the attribute code overlay on top of the source map. Check to ensure that all areal and linear features have been correctly labeled. For a simple map, place both the feature and attribute code overlays on top of the map and edit both at the same time. When every feature is properly drawn and categorized, the map is ready to be registered.

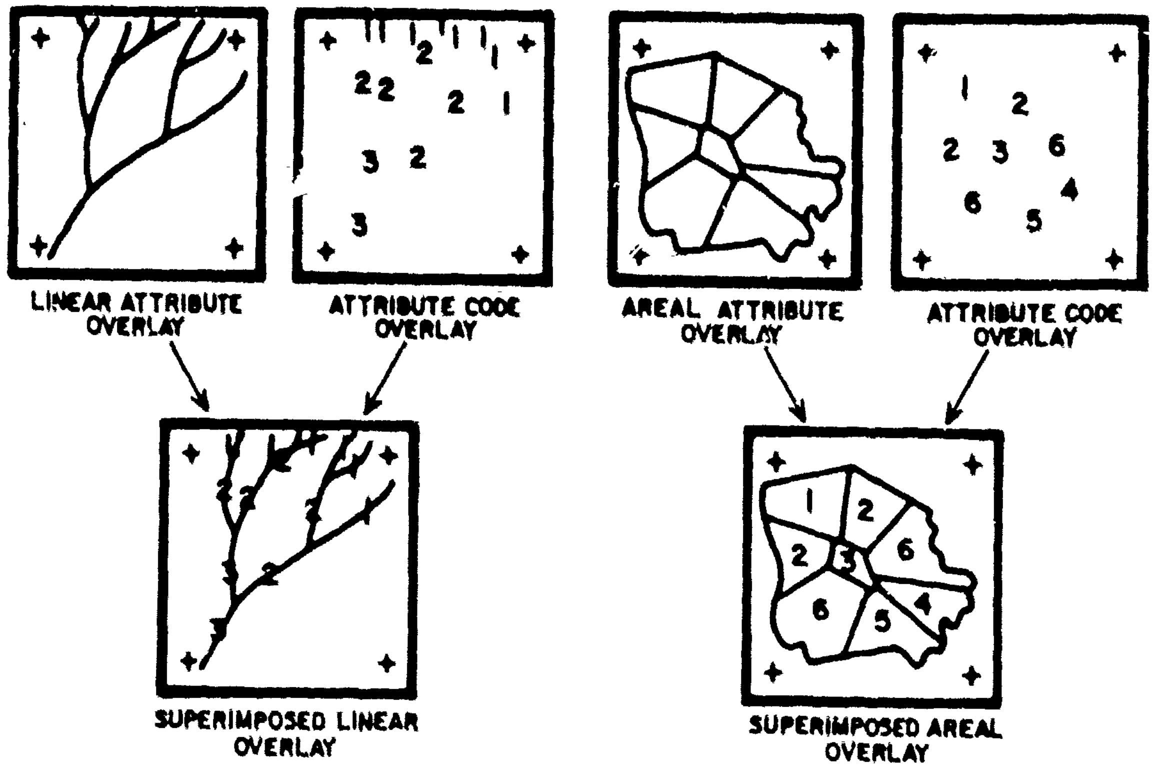


Figure 9. Coding linear and areal attributes.

Map Registration

Before a map can be digitized, it must be registered so the digitizing table "knows" how the map is oriented on the table, and to establish a relationship between the coordinates of the source map and those recorded by the digitizing table. This step is especially important because it connects the graphic representation to an actual geographic location, which is the advantage of a GRASS database over a simple picture, such as those created by non-GIS graphics software.

Marking Reference Points

Before the map is registered, reference points must be marked on the source map. This process differs slightly depending on whether the map is to be manually digitized or electronically scanned.

For manual digitizing, reference points must be in the same units as the database. For example, the unit will be meters when the UTM system is used. (See *The UTM Coordinate System* in Chapter 4 for a description of the UTM system.) For the many standard topographic maps that already include a UTM grid system, simply copy the intersection of a Northing and Easting grid line in each corner of the map. While only four points are needed to register the map, up to 10 points dispersed over the map may be used. Using a pencil, make a small cross mark at each corner of the map to show the intersection of the grid lines. These points are then traced onto the mylar overlays (Figure 10a).

For automatic scanning of a map, the UTM reference points must be established in the four corners outside the project area. Most scanning companies request only four points. If the entire map is the project area, the coordinate system must be extended beyond the map's borders. This is done by measuring with a ruler the distance between two successive Northing grid lines, and two successive Easting grid lines. At the northern edge of the map, measure one UTM grid distance north from the outermost Northing grid line. Using a pencil, mark that distance at two or three points parallel to the outermost Northing line. Align the edge of a long ruler with the pencil marks, and draw the new Northing line. Repeat this procedure at the southern, eastern, and western edges of the map. The reference marks are then established in each corner, outside the project area, by tracing the intersections of the newly established Northing and Easting grid lines (Figure 10b).

Sometimes the project area traverses two UTM zones. On a large-scale map, there will be a 25-mile overlap between zones (1 mile = 1.609 kilometers). GRASS is not capable of interpreting maps from more than one UTM zone unless one zone's coordinate grid is extended to label the portion of the map from the other zone. This is illustrated by the dashed lines extrapolated from the left half of the map into the right (Figure 11).

Residuals and Map Registration

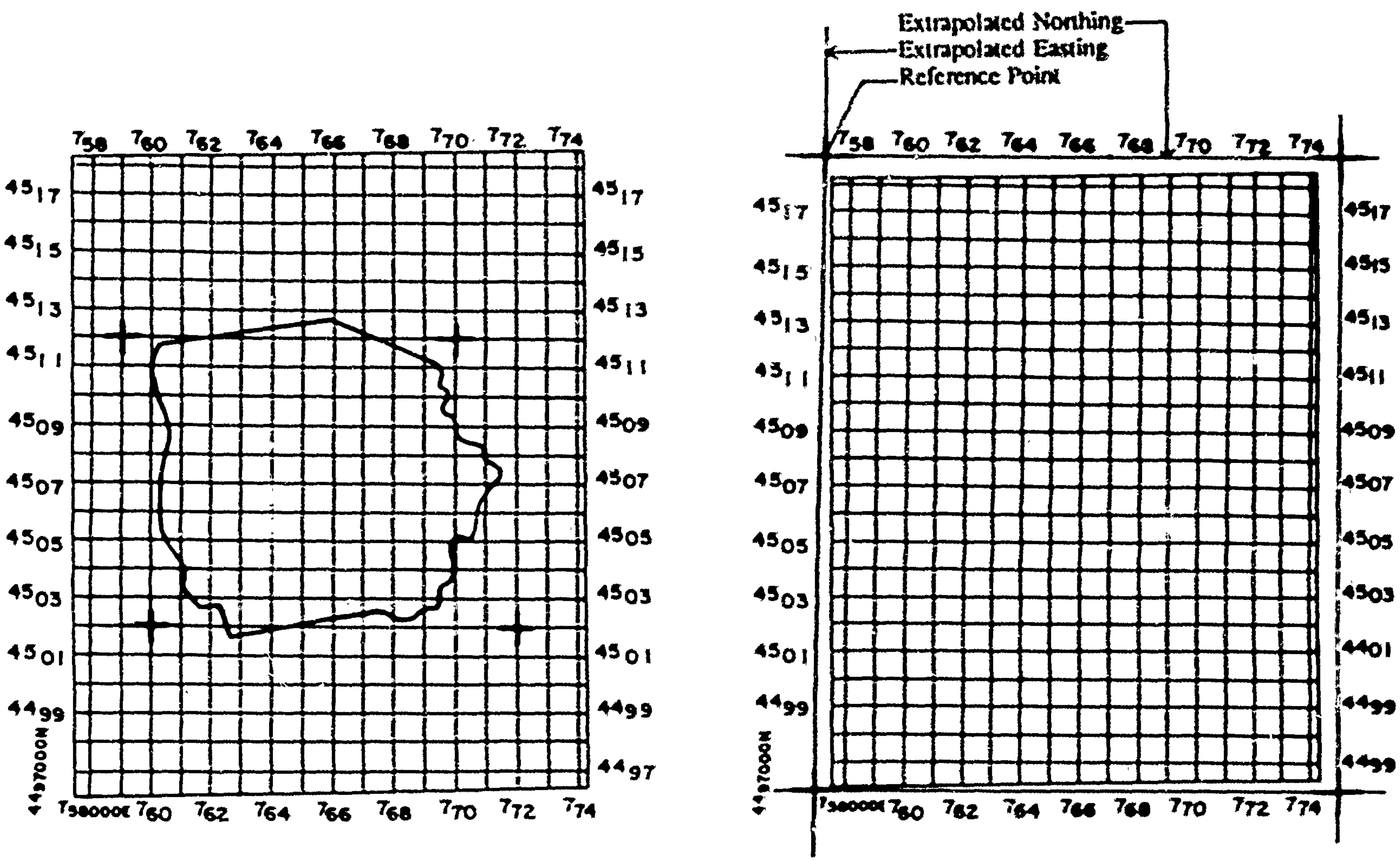
When the map is ready, it is set up on the digitizing table. When prompted by the GRASS *digit* program, the operator enters map coordinates for the reference points, then uses the digitizer's cursor to record their table locations. The locations of these points are processed to establish the relationship between the two coordinate systems. The difference between the values that the table coordinate system "expects" from the map and the actual values entered for the registration points result in residuals, which are listed beside each registration point. These residual values, which indicate the degree of a map's inaccuracy, are given in map units (meters). The value of residuals varies with the scale of the map.

The *digit* program can accurately register a map with four points, one from each corner of a relatively accurate map. In cases where the map to be digitized is a composite of several source maps, however, it is a good idea to take one or two points from each component of the composite.

When registering a map using the GRASS *digit* program, residual values should be kept as low as possible. Since residuals are presented in map units, the acceptable value will vary with scale. The best maps generally give lower residuals than less accurate maps at the same scale.

Table 2 gives some general guidelines for evaluating residual values. The first column of suggested values is suited to maps that are nearly ideal. The best source maps are of known accuracy and in excellent condition—not folded or worn. An example might be a recent 1:24,000 USGS paper quad sheet in good condition, or an acetate separate of it. The table's second column of values is suited for the cases in which the source materials are less ideal. Perhaps several maps have been used to create the drafted copy to be digitized, or maybe some of the source material is of dubious accuracy. During map registration, it is best to continue trying different registration points until the residuals reach acceptable levels. *Digitizing a map without proper registration will cause serious inaccuracies in the coordinate values of the resultant digital map.*

A useful rule of thumb is to keep the average of all residual values to the middle or lower end of the ranges indicated in the table. No single residual should exceed the upper range. If it is impossible to get the residuals to this level, the map may be too inaccurate to include in the database in its current form. No amount of adjusting the registration will bring an inaccurate map any closer to representing true ground coordinates. (See *Improving Map Data* in Chapter 4 for ways of improving the quality of map data before it is added to a GRASS database.)



a. For a map to be manually digitized.

b. For a map to be scanned.

Figure 10. Reference points.

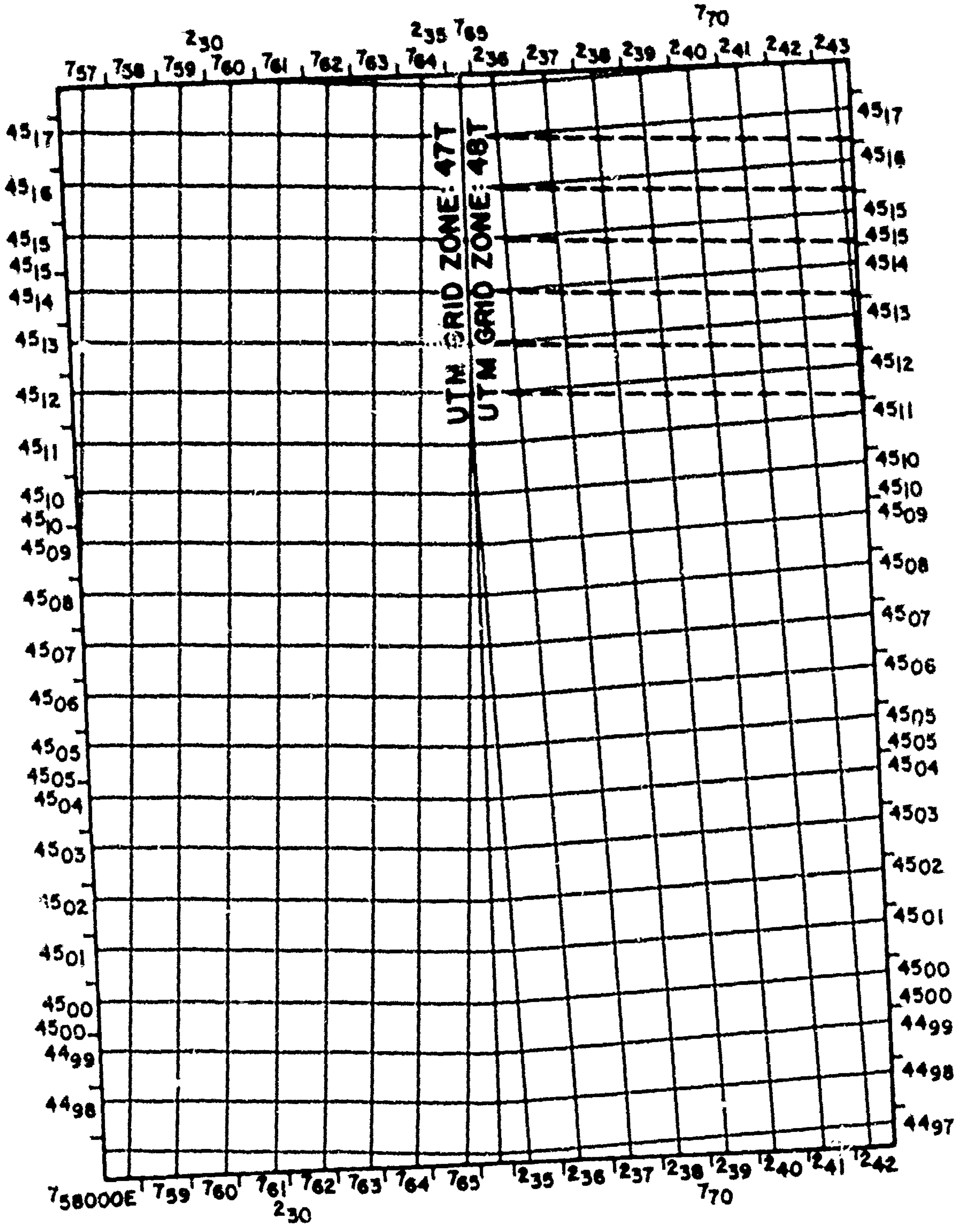


Figure 11. Extension of one UTM grid zone into another. (Source: Field Manual [FM] 21-26, Map Reading [Headquarters, Department of the Army, 1965], pp 3-18, 3-19.)

Table 2

Acceptable Range of Residuals When Digitizing from Maps

Map Scale	Residuals for Most Accurate Maps	Residuals for Less Accurate Maps
1:100,000	20 - 30 meters	45 - 60 meters
1:50,000	5 - 10 meters	20 - 30 meters
1:24,000	1.2 - 2.4 meters	7 - 12 meters
1:4800	.5 - 1.0 meters	2 - 4 meters

It should be noted that it is possible to achieve a low residual average and still have inaccurate registration. To check for this possibility, the GRASS *digit* program provides an option that allows the user to move the digitizer cursor around the map and preview the coordinate values anywhere on the map. If these points seem inaccurate, the user should try to find better registration points.

Another way to test the soundness of the map's registration is to make a test printout, called a "proof plot," which is compared with the map data being digitized. The user can digitize a few long lines from the map data, then plot them and compare them to the source. If they exhibit noticeable distortion, the registration is suspect. Otherwise, digitizing can continue using the current registration points.

These procedures may sound too difficult to be practical, but need to be done only one time for each map. Once the registration points have been established and verified, the same points are used each time the map is digitized.

Special Issues in Digitizing

This section discusses some special aspects of capturing digital data from printed maps, including thresholds, snapping, and residuals.

Digitizing Threshold

Digitizing with the GRASS *digit* program may be done in either "point" or "stream" mode. In point mode, a point is recorded at each location specified by the operator. In stream mode, points are recorded automatically and continuously as the operator traces the line. When digitizing in stream mode, the equipment often picks up more points than are needed to adequately depict a line. To keep the size of data files recorded in stream mode manageable, a "pruning" of unnecessary points occurs before the data is saved. The term *digitizing threshold* describes a measurement that GRASS employs to decide which points to save and which to delete.

Pruning occurs each time the operator "accepts" (saves to disk) a line. GRASS achieves this by setting up a directional corridor the width of the digitizing threshold (Figure 12). The direction of this corridor is determined by the first two points collected by the digitizer. GRASS examines all subsequent points to determine whether they fall within the corridor's limits. When a point lies outside the corridor, GRASS interprets this as defining a new direction for the line. The program saves the first point of the current line segment and the last point that falls inside the same corridor. The intervening points are considered unnecessary to define the line segment and are discarded. A new corridor is then established between the second saved point and the point collected immediately after it. This process continues as necessary.

As a result of this process, a curved portion of a linear feature will contain more points than a straight line segment. In cases where the straight line segments are short and interspersed with curves, digitizing in stream mode is about as efficient as in point mode. However, it is not recommended that long, straight line segments be digitized in stream mode, because they are done more efficiently in point mode.

The default digitizing threshold is 0.03 inches, or about 0.75 mm (1 inch = 25.40 millimeters). This threshold works quite well for digitizing complex curved lines. If the default threshold is not satisfactory, it may be changed using the *digit* "Customize" menu. A larger threshold (e.g., 0.05 inches) will result in fewer points being saved; a smaller threshold (e.g., 0.02 inches) will result in more points being saved.

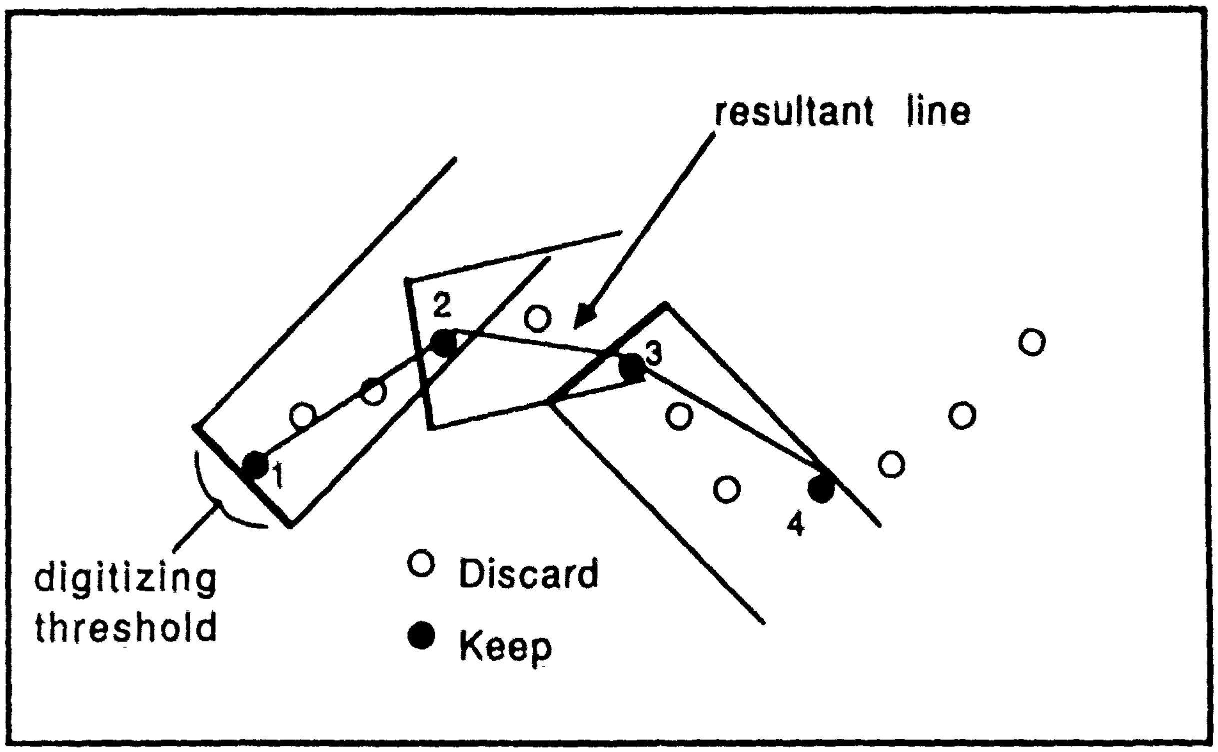


Figure 12. Digitizing threshold.

Map Threshold

The term ***map threshold*** describes the same parameter as digitizing threshold, but because it is measured in map units, it is directly related to the map's scale. For example, suppose a map is being digitized using the UTM coordinate system. Map units would, by definition, be meters. The default digitizing threshold of 0.03 inches equals 0.000762 meters. If the scale of the map being digitized is 1:24,000, the map threshold would be 0.000762 multiplied by 24,000, or about 18.29 meters A map scale of 1:50,000 would give a default map threshold of 38.1 meters.

The map threshold may not be changed directly. It changes automatically with the digitizing threshold.

Snapping Threshold

In vector maps, by definition, two arcs are connected by a node. If two nodes are sufficiently close to one another, they will automatically merge, or "snap," into a single point. The widest distance at which snapping will occur is called the ***snapping threshold***. The two arcs connected to snapped nodes will join at those nodes. In general, the node that is second in order in the file will snap to the one that is first. The default snapping threshold is 0.04 inches. As with the digitizing threshold, the snapping threshold is usually measured in distance as measured on the map. Occasionally, however, it is expressed as distance on the ground. When expressed as distance on the ground, the number given for the snapping threshold depends on the scale of the map.

The main purpose of the snapping threshold is to make it possible for the operator to end one line and start a connected one at the "same" node even though that point on the digitizing table actually represents two nodes in the database. For the purposes of digitizing, GRASS treats any two nodes within the snapping threshold as a single node.

In most cases, the default snapping threshold is sufficient, but it may be changed using the *digit* "Customize" menu, if necessary. There may be a situation when two nodes must be closer than the snapping threshold allows. The user may want to capture the data the two nodes represent, but *digit* wants to merge them. Lowering the snapping threshold keeps the nodes separate. In such a case, it is best to leave the snapping threshold at the lower value when the file is saved.

The snapping threshold may also need to be changed when importing a foreign vector file into a GRASS database. Different systems handle snapping differently, so a new file from an external source may not snap according to GRASS standards. GRASS requires shared nodes to have exactly the same coordinate values. If it is known that a vector file is not snapped, the user may allow it to snap when running the GRASS program *import.to.vect*. Snapping in such circumstances occurs at the default snapping threshold.

If the exact snapping status of a foreign vector file is not known, the user should first run *import.to.vect* without allowing the nodes to snap. Then, if problems that might be related to snapping are observed, the GRASS program *support.vect* may be run. With this program, the user may assign a snapping threshold or use the default.

Caution: When running *support.vect*, the user should be careful about setting a snapping threshold higher than the default value. An overly high threshold could cause nodes to be inappropriately snapped, seriously distorting the data file. This could be especially problematic if the file has not been backed up.

4 CARTOGRAPHIC CONSIDERATIONS

To develop an accurate and useful cartographic database, GRASS users must know the basics of map scale, coordinate systems, and map projections. They should also know the options for improving the horizontal accuracy of inaccurate source data.

Map Scale

The proportion of real distance on a map to actual ground distance is called *map scale* (Figure 13). Data developers must refer to the map scale several times during the development of a GRASS database.

Map scale can be expressed several different ways. Scale as a representative fraction defines a ratio between the map's dimensions and the earth's surface, but employs no unit of measure. For example, the map scale 1:24,000 means that 1 unit of measure on the map equals 24,000 of the same units on the earth. The ratio applies to any unit of measure. Thus, 1 in., 1 cm, or 1 mm on this map is equivalent to 24,000 in., 24,000 cm, or 24,000 mm, respectively, on the earth.

Another way of expressing scale is with a graphic, or bar, scale. A bar (or line) is drawn on the map and calibrated to show how many units of a specific measure it represents (Figure 14).

A third way to represent map scale is with a simple statement, such as "1 inch equals 10 miles."

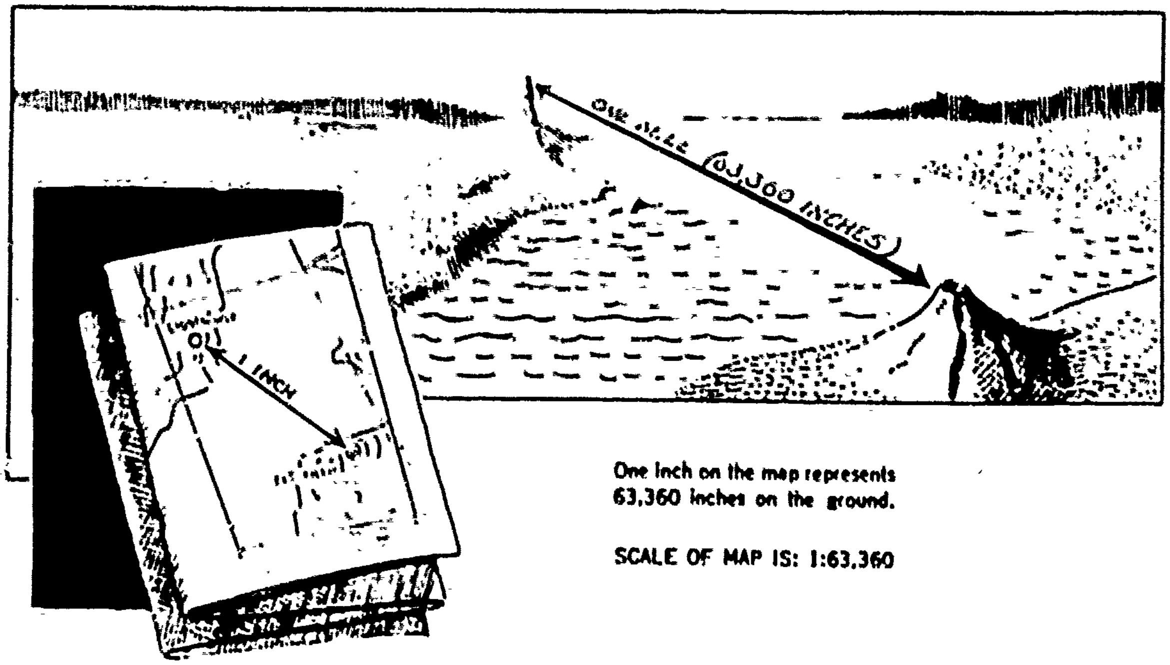


Figure 13. **Visual depiction of scale.** (Source: Army Map Service [AMS] Training Aid No. 6, *Map Intelligence*, 2d Edition [U.S. Army Corps of Engineers, 1954], p 72.)

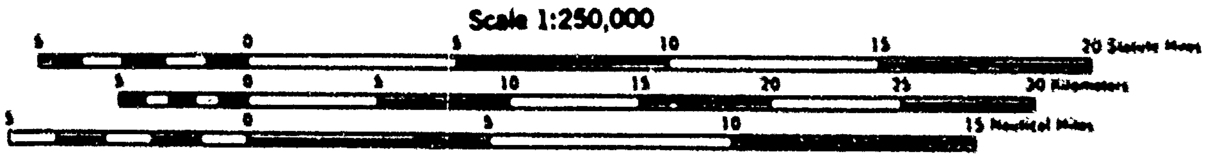


Figure 14. Bar scales. (Source: 1:250,000 map of Brunswick, GA, prepared by U.S. Army Corps of Engineers AMS [USGS, revised 1968].)

Transforming Map Scales

While all three forms of map scale are commonly used on printed maps, the GRASS digitizing program requires the user to supply a representative fraction. Therefore, any other type of scale representation must be converted to a representative fraction. (See Appendix B for a table showing conversions for different map scales.)

If a conversion table is not available, the user must calculate the conversion. This is simply a matter of transforming an expression of scale into a fraction that applies to any unit of measure. The scale "1 inch equals 10 miles," for example, is first expressed as a fraction:

$$\frac{1 \textit{ inch}}{10 \textit{ miles}}$$

The next step is to convert the numerator and denominator into common units—inch-miles, in this example. It is easily established that 1 mile equals 63,360 inches. This relationship expressed as a fraction has a net value of 1. Therefore, this second fracton can be multiplied by the first without altering the ratio expressed by the first:

$$\frac{1 \textit{ inch}}{10 \textit{ miles}} \times \frac{1 \textit{ mile}}{63{,}360 \textit{ inches}} = \frac{1 \textit{ inch mile}}{633{,}600 \textit{ miles inches}} = \frac{1}{633{,}600} \textit{ or } 1{:}633{,}600$$

Notice that the second fraction is expressed with miles in the numerator and inches in the denominator. This neutralizes both units of measure when the fractions are multiplied and the product reduced. The result is a fraction with no units of measure.[9]

Large Scale vs. Small Scale Maps

The terms *large scale* and *small scale* are often misunderstood. They refer to the relative size at which geographical features are represented on a map. A large-scale map shows relatively more detail for a relatively smaller geographical area. A small-scale map shows the opposite: less detail over a larger geographic area. There are no fixed standards for what is large scale or small scale. The Army suggests the following rules of thumb:

[9]A. Robinson, R. Sale, and J. Morrison, *Elements of Cartography*, 4th ed. (John Wiley and Sons, Inc., New York, 1978), p 45.

- large scale—larger than 1:75,000
- medium scale—smaller than 1:75,000 and larger than 1:600,000
- small scale—smaller than 1:600,000

On the other hand, the USGS classifies its maps like this:

- large scale—1:24,000
- intermediate scale—1:50,000 and 1:000,000
- small scale—1:250,000, 1:1,000,000, and 1:2,000,000

Engineers or city planners may consider a map scale smaller than 1:4800 (1 inch = 400 feet; 1 foot = 0.3 meters) too small for their purposes, while many foresters, by custom and convenience, feel most at home with a scale of 1:15,840 (4 inches = 1 mile).

Scale and Digital Databases

Although no ideal map scale exists for all purposes, some important principles about map scale for digital databases should be emphasized. A major criticism of digitizing map coordinates is that it may be too easy to misuse the data out of ignorance. For example, when source material is compiled during the manual construction of a map, a cartographer usually tries to select material for the base map at the same or, preferably, larger scale than the compilation. This way, when the final map is printed, its level of detail is consistent with its scale. It is acceptable to generalize from more detail to less, but it is not a good idea to generalize from less to more, because that creates the appearance of more detail than the data holds, and can result in serious inaccuracies. Yet, once map information is digitized, the computer offers limitless possibilities for this kind of inappropriate manipulation.

Consider a hypothetical GRASS database in which several layers — roads and streams, for example — are based on USGS 1:24,000 quad sheets. Other layers that define the boundaries of a military installation and its training areas, come from maps at a scale of 1:50,000. Combining map sources of these two scales will cause problems. The boundaries may actually follow the roads or streams, but when the data from the two sources are overlaid, their lines do not match.

In some GISs it may be simple to "force" the lines to match by directly copying them from one layer to another. This is not easily done in GRASS, in part because it is not a good idea. In GRASS, the user of this hypothetical database may use the layers as they are, ignoring the sloppy appearance of lines that don't match. Another option would be to back up a step and redigitize the boundaries from the 1:24,000 quads. If the boundaries are not available there, they might be recreated on the 1:24,000 base map from all information available from other sources. When the newly compiled map is digitized, it will fit with the other layers.

The problem of mixed scales can get even more complex. Suppose the map of soils for the hypothetical subject area above is available only at a scale of 1:100,000. Creating a new soils map is prohibitively expensive. Even recompiling the map from other sources (including a soil scientist familiar with the subject area), and at a larger scale, may not give acceptable accuracy at a scale of 1:24,000. And even this approach may be possible only as a long-term option. As undesirable as this situation is, it is entirely possible.

It is important for the user of the data to be aware of such problems. Information about the original soils map scale is supposed to be available by running the GRASS program *layer.info* (and will be there if the creator of the map originally entered it). Based on this information, the user should realize that a hard copy of that layer, printed at 1:24,000, would not contain the detail or degree of accuracy that is usually expected of a soils map at that scale. Also, if that layer were used with others at the larger scale, the soil information would correlate only roughly to the information from the larger-scale maps. Any application of this data must consider the inconsistency of scale built into the database. Unfortunately, the computer allows many more possibilities for manipulating the data than does sound judgment.

Map Scale for "Maplike" Products

A different way to consider map scale arises with aerial photography and satellite imagery. Although these products are created at a specific scale, they may be safely blown up to the limits of the original. Unlike a printed map, the graphic details exist at the original scale; they simply need to be brought out by enlargement. There is a limit, of course, to how much an image can be enlarged. In photography, for example, the limit will be determined by the resolution and quality of the film, the focal length of the lens, atmospheric conditions, and flying height of the aircraft.

With satellite images, scale has meaning only in relation to the printed forms, not the digital data. Because of its nature, digital imagery is best discussed in terms of its spatial resolution, or pixel (cell) size. The cells represent a specific size, expressed in meters, that indicates the area of ground depicted by that cell. The resolution of a cell map in GRASS works on similar principles.

Tables 3 and 4 outline some important parameters for several common photographic and satellite products. The altitude of any craft, whether airplane or satellite, tends to vary slightly in the course of a flight. The numbers given in the table are for the programmed altitudes.

Obviously, one must know more about the products in the table to make good decisions about their use. This explanation is only intended to show the relationship between map scale and a GRASS database.

Table 3

Scale and Resolution of Common Photographic Products

Aerial Photography from the U.S. Geological Survey			
Product	Scale	Focal Length	Flying Height
NHAP CIR	1:58,000	8.25 in. (210 mm)	40,000 ft (12,192 m)
NHAP B&W	1:80,000	6 in. (152 mm)	40,000 ft (12,192 m)
NAPP CIR	1:40,000	6 in. (152 mm)	20,000 ft (6096 m)
NAPP B&W	reproduced from NAPP CIR		

NHAP CIR = National High Altitude Program Color Infrared
B&W = Black and White
NAPP = National Aerial Photography Program

Table 4

Resolution of Common Satellite Products

Product	Satellite Imagery Spatial Resolution	Altitude over Equator
SPOT B&W	10 m	832 km
SPOT 3 band multispectral	20 m	832 km
LANDSAT 1,2,3 MSS	79 m	917 km
LANDSAT 4,5 MSS	79 m	705 km
LANDSAT 4,5 TM	30 m	705 km

SPOT = Satellite Probatoire pour L'Observation de la Terre
LANDSAT = Land Satellite
MSS = Multispectral Scanner
TM = Thematic Mapper

Coordinate Systems and Projections

Coordinate systems and projections are both essential components of any map. A projection is a method of transferring geographic information from the earth's curved surface to a flat map. A coordinate system provides a means for establishing the location of any point in relation to other points. Examples of such systems include the UTM grid system, the State Plane Coordinate systems, geographic coordinates (latitude and longitude), and a simple cartesian coordinate (x,y) grid. A less common system, used by several GRASS programs, is the geocentric coordinate system. These coordinates describe a geographic location in dimensions x, y, and z, with the origin at the center of a spheroid representing the approximate shape of the earth.

Different coordinate systems have been worked out using different projections, but the most common one used in GRASS is the UTM grid, based on the Transverse Mercator projection. The State Plane systems are based on either the Transverse Mercator or Lambert's conic projections. The geographic coordinate system of latitude and longitude may be used with any projection. In general, a projection must first establish how the curved earth will be represented on a flat surface before any coordinate system can be applied.

GRASS does not fully support either State Plane systems or geographic coordinates, but efforts are being made in that direction. Two GRASS programs (*Mll2u, Mu2ll*) convert UTM coordinates to latitude and longitude, and vice versa. Other programs (*Mll2gc, Mgc2ll*) convert both ways between geographic and geocentric coordinates. Most GRASS programs work with UTM grids, however. (One notable exception is a cartesian coordinate system used for raw imagery data, where x indicates the row and y indicates the column of a grid cell, with the origin in the lower left corner.)

The UTM Coordinate System

Because the UTM grid system is the predominant coordinate system used by GRASS, it is worthwhile to describe it in some detail. The UTM grid system is keyed to the earth between 84 degrees N latitude and 80 degree S latitude. It longitudinally divides the earth into 60 zones, each 6 degrees wide. The zones are numbered 1 through 60 starting at the 180th meridian. Each zone is divided into 20 eight-degree sections, each of which is lettered alphabetically C through X from south to north (excluding I and O). Each 6- by 8-degree rectangle of earth is uniquely identified by its column (zone) number and row letter (Figure 15a). Each north-south and west-east UTM grid line is referred to as an "Easting" and a "Northing" respectively, and is assigned a value in meters. Distances using a UTM grid system are always measured left to right and bottom to top (Figure 15b). The spacing interval of a UTM grid on a standard USGS topographic map depends on the scale of the map (Table 5).

The UTM system was chosen to be the dominant system in GRASS for two reasons. First, the system was already familiar to personnel at Army installations, who were the first users of GRASS. This familiarity has helped link the new GIS technology to the methods it is replacing. Second, but equally significant, the UTM system is expressed as a plane. The distance between two grid ticks is constant in both directions x and y. For practical purposes, the section of the Earth being studied is considered to be a plane. This practice is acceptable for one relatively small area at a time. Note that the geographic coordinate system, which is designed for a sphere, does not share this characteristic. A degree of longitude at the equator represents a much larger distance than a degree of longitude near a pole. Plane geometry is much simpler than spherical geometry, so using UTMs as the primary map unit allows GRASS programs to be simpler. These factors, as well as its relatively easy usage and widespread acceptance, made the UTM grid system the natural first choice for GRASS.

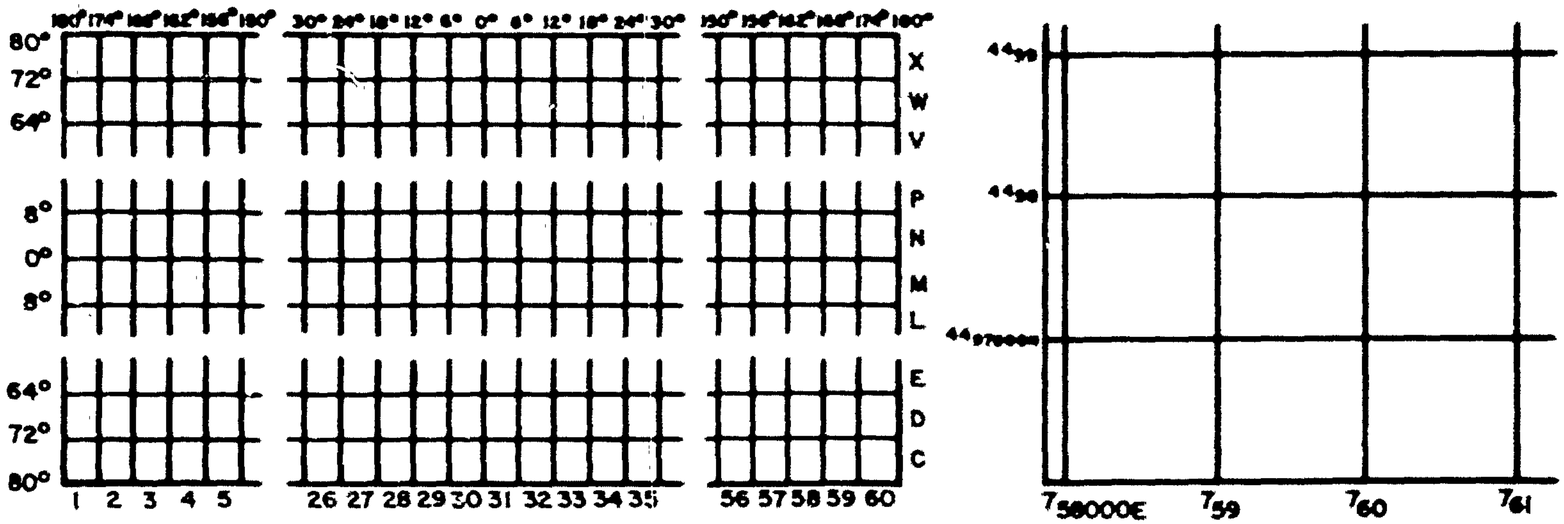
When the UTM system is used, the user is expected to choose source materials that use a projection compatible with the UTM coordinate system. The GRASS user, in turn, usually expects the creator of the source map to have chosen a projection responsibly before placing the grid on top of it. The user should be wary of a UTM grid drawn on aerial photographs uncorrected for distortion or small-scale maps. The grid is not likely to indicate accurate ground coordinates, and this can cause trouble-especially when more accurate maps are overlaid on it.

When the UTM system is used with the GRASS a special problem can arise. A GRASS database may not extend east to west beyond one UTM zone, or 6 degrees. This problem is not easily solved. If the study area extends only a relatively small distance beyond the zone, the grid numbers can simply be extended. This approach is unacceptable beyond a limited area, however, because distortion caused by the Earth's curvature increases as one moves farther from the central meridian of any zone. Another possible solution is to make separate databases for the parts in different zones.

Maps of large areas have sometimes been digitized using an artificial UTM grid. In such cases, the study area was simply overlaid with a grid, measured in meters, that bears no relationship to actual UTM coordinates. This method results in a map without true ground coordinates, making it difficult to add data from other sources.

When the Source Has No UTM Grid

As stated in Chapter 3, the process of map registration establishes the UTM coordinates for a map. If there is no UTM grid on a map that is needed for a GRASS database, however, the user has several alternatives.



a. UTM grid zone designations.

b. Grid lines within a UTM zone.

Figure 15. UTM coordinate system.

Table 5

UTM Reference System Spacing for USGS Topographic Maps

Map Scale	Grid Spacing (m on ground)	Spacing (on map) in.	mm
1:20,000	1,000	1.97	50.0
1:24,000	1,000	1.64	41.6
1:25,000	1,000	1.57	40.0
1:50,000	5,000	3.94	100.0
1:62,500	5,000	3.15	80.0
1:63,360	5,000	3.10	78.7
1:100,000	10,000	3.94	100.0
1:250,000	10,000	1.57	40.0
1:500,000	50,000	3.94	100.0
1:1,000,000	100,000	94	100.0

Source: Morris M. Thompson, *Maps for America* (U.S. Geological Survey, 1979), p 24.

If another type of coordinate system has been established on the map, there are several ways to establish a UTM coordinate system. For a map that uses only latitude and longitude, the user can employ the GRASS program *Mll2u* to enter the latitude and longitude coordinates. GRASS then assigns UTM Northing and Easting equivalents to the grid. GRASS can currently provide UTM conversion for latitude and longitude only. If a State Plane coordinate system is the only system established on the map, the user can obtain software that converts that system into latitude and longitude, or find someone to perform the conversion. The user may also use a UTM map covering the same area to determine the UTM coordinates for points on the State Plane map.

A different approach is needed to register an aerial photograph without a UTM grid, such as an SCS soil survey. Often the scale is inconsistent across such photos. Some distortion is due to relief displacement, and some is due to the nature of aerial photography. The following approach should be used only in cases where the terrain is relatively flat and the photographs are recent, or when an orthophotograph was used to map the soils. (An orthophotograph is a photo including all the graphic information of an aerial photograph with the constant scale of a map.) In other cases the user should recompile the soil information on a base map with an accurate x,y relationship among features. (See the section *Improving Map Data*, later in this chapter, for information on recompiling soil maps.)

There are two ways to identify UTM reference points on aerial photos without a UTM grid. For one procedure, the user needs a map that covers the area of interest on the photo. The user needs to find reliable landmarks on the map that can be recognized in the photograph. Reliable landmarks are features that are accurately placed on the map, such as a road intersection or a sharp bend in a road. Unreliable landmarks include features such as a well, water tower, church, or stream. The first three examples are unreliable because they are generally not placed on a map with great accuracy. A stream is not reliable because its shape changes with time, and much time may have passed between the date the map was drafted and the date the photos were acquired. When at least six dispersed reference points on the photograph are identified on the map, determine the UTM coordinates of the points on the photo. An easy way to do this is to use the manual digitizing unit and GRASS's *sites* option. (The tutorial "digit; Its Use and Its Features" offers a detailed explanation of how to use this software.) When the coordinates for the points have been determined, they can be transferred onto the photograph.

When working with aerial photographs, there are two reasons to choose at least six reference points. First, due to the inherent nature of photographs, the picture is more distorted at its edge than its middle. By choosing at least six points, one can be more certain that the reference points are a fair representation of the photograph. Second, during the manual digitizing process, at least four points are needed to register a photograph or map. By using more than four points from the photograph during registration, the user can remove the points with the highest registration residual values. (See the section *Residuals and Map Registration*, in Chapter 3, for more information on residual values.)

A second way to establish registry points on an aerial photograph requires a map covering the same area, and of the same scale, as the aerial photo. Tape a piece of mylar on top of the photograph. Then, in blue pencil, trace some of the roads and intersections from the photo. There is no need to trace all of the roads, only enough to cover dispersed areas on the photograph. Then remove the mylar and tape it on top of the map, aligning the roads traced from the photograph with the roads on the map. The roads will not align exactly, so "spread out the error" by slightly offsetting all roads on the overlay with the roads on the map (Figure 16). Establish the registration points using the grid system from the map under the overlay. Finally, take the overlay, realign it to the roads on the photo, and tape it down so the features on the photo can be traced and manually digitized.

In many cases, the user will need to create a mosaic of photographs to completely cover the area of interest. As mentioned earlier, photographs are most distorted along their edges, so they will not match up perfectly. In these instances, "spread out the error" along the common edge (Figure 17). Once the "mosaic" is completed, locate the reference points needed to register the composite. If the features taken from the photograph are to be scanned, the reference points must be established outside the area of interest.

Accuracy and Quality in a GRASS Database

It is important that the data used to build a GRASS database be as free from error as possible. The required degree of accuracy varies, however, depending on the application of the data. Map accuracy is a complex topic. The GRASS user must avoid introducing error when possible, and appreciate the limitations of map data in general. These limitations involve the source material and the way data is digitized and entered into a database.

The Accuracy of Source Materials

Never assume that any source, whether a printed map, aerial photograph, or satellite image, is free of error. Each source has problems affecting its suitability for any given application. The size of the paper on which maps are printed, for example, is not stable over time. It can expand in humidity as much as 1 percent.[10] It is always best to obtain map information on a stable base material such as plastic when

[10] P. Snyder, *Map Projections; A Working Manual*, U.S. Geological Service Professional Paper 1395 (U.S. Government Printing Office, Washington, D.C., 1987), p 3.

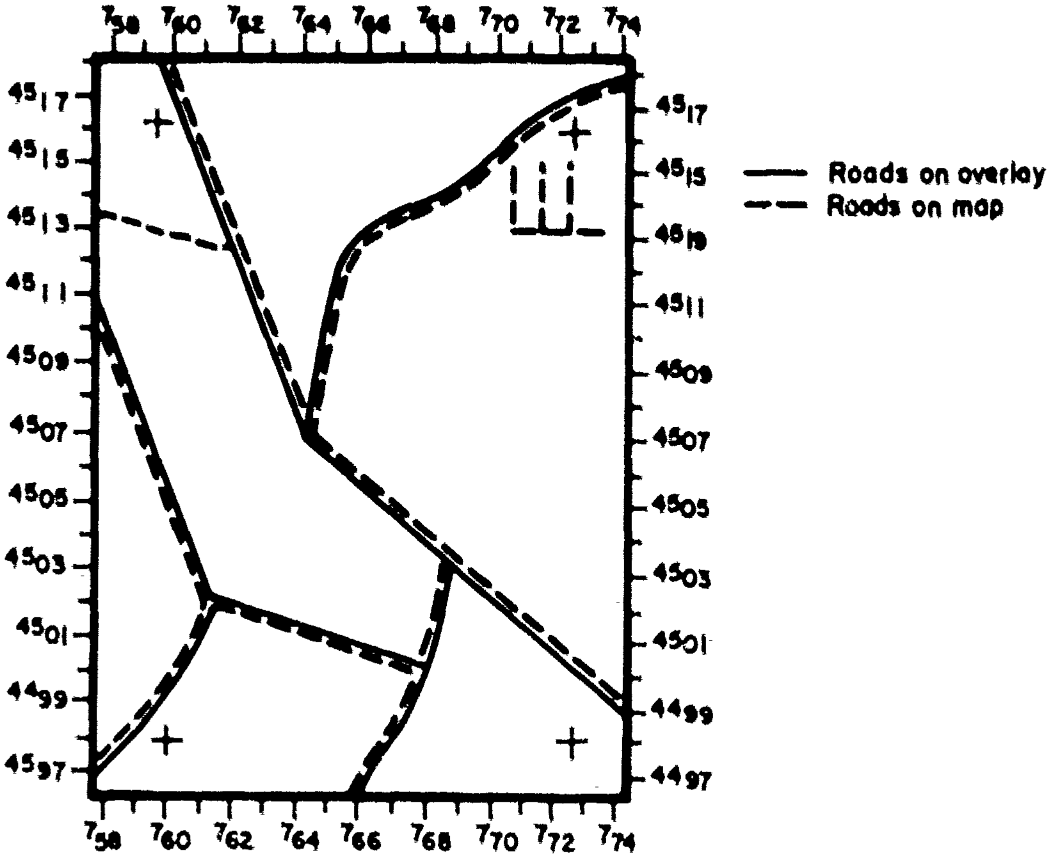


Figure 16. Aligning overlay to map.

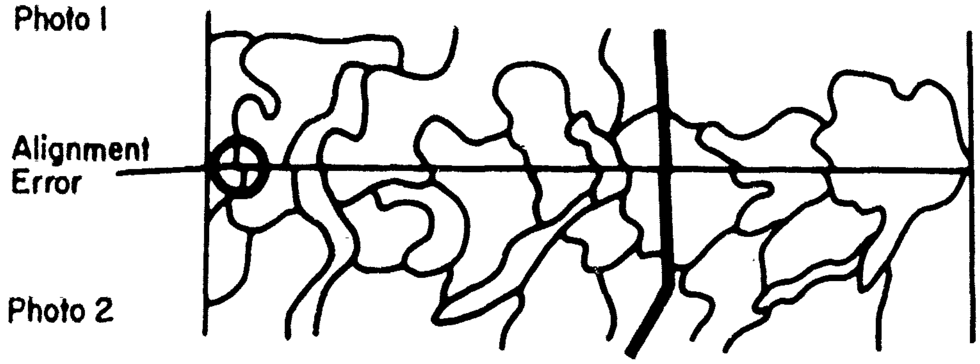


Figure 17. Aligning adjoining aerial photographs.

possible. In general, the accuracy of a map's contents is never guaranteed. Soils maps are usually considered to contain about 15 percent error due to the ambiguity of divisions between various soil properties.[11]

Another issue of importance is the horizontal accuracy of locational data. It depends on the quality of the original control survey and the quality of map production and reproduction processes. Some maps have been tested and found to be within the margin of error allowed by National Map Accuracy Standards (NMAS). If NMAS testing has been done, a statement to that effect is printed in the margin of the map. If these standards have been met, the map was almost certainly produced under very strict control. Information taken from it is probably as reliable as can be expected from any map at the same scale. If no NMAS statement is printed on a map, the map has either not met the standards, or it has not been tested.

The United States NMAS for horizontal accuracy state that no more than 10 percent of well defined points shall be in error of more than a specified amount (depending on map scale), as measured on the map. The amount is 0.03 inches for maps of scale larger than 1:20,000 and 0.02 inches for maps of scale smaller than 1:20,000. These amounts represent different ground distances, depending on map scale (see Table 6). Note that these standards are meaningful for a fairly limited range of scales. At very large scales, the error allowed is greater than what might be acceptable; at smaller scales, maps with precise horizontal accuracy can not be expected. For vertical accuracy, NMAS state that, for any map scale, no more than 10 percent of the tested elevation points shall be in error more than the value of one half of a contour interval.[12].

Another way to define map accuracy is by use of a reliability diagram. The example in Figure 18 shows such a diagram from a USGS 1:250,000 scale map of Georgia. It does not give a quantitative measure, but provides a qualitative index for assessing the potential usefulness of the map.

Table 6

Map Scale and Horizontal National Map Accuracy Standards

Map Scale	Distance on the Map	Distance on the Ground
1:15,840	0.03 in. (0.76 mm)	40 ft (12 m)
1:24,000	0.02 in. (0.51 mm)	40 ft
1:50,000	0.02 in.	83 ft (25 m)
1:100,000	0.02 in.	166 ft (50.8 m)

[11] P.A. Burrough, *Principles of Geographical Information Systems for Land Resources Assessment* (Clarendon Press, Oxford, 1986), p 108.
[12] A. Robinson, R. Sale, and J. Morrison, pp 8-9.

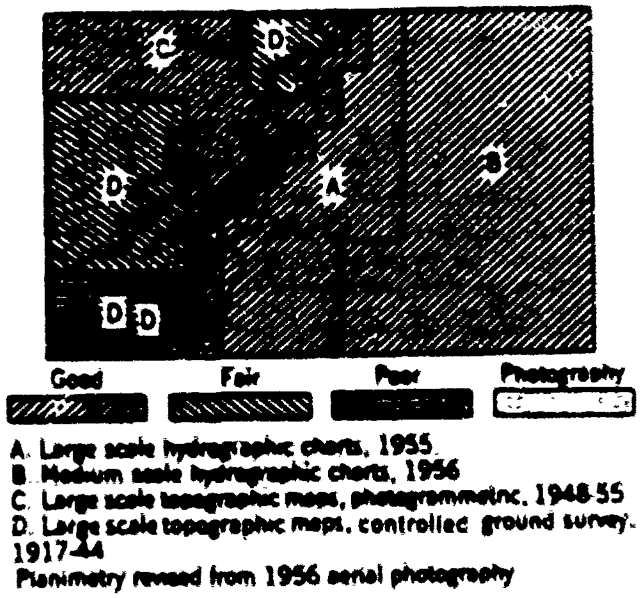


Figure 18. Reliability Diagram. (Source: 1:250,000 map of Brunswick, GA, prepared by U.S. Army Corps of Engineers AMS [USGS, revised 1968].)

In many cases, no statement of accuracy is available. This should be noted in the documentation for the GRASS map layer. It is helpful to include any other information about the source data that would help the end user accurately judge its value. Such a report might include justification for the use of a source of questionable accuracy.

Improving Map Data

Sometimes the sole source of certain map information will be known to have poor horizontal accuracy. SCS soil atlas sheets, for example, contain very valuable data collected at considerable expenditures of time and money, but they have a serious weakness: the soil polygons were usually drafted directly onto aerial photographs uncorrected for distortion, and offer no guarantee of horizontal accuracy. Data developers have two options that may improve the information before it is entered into the database.

One method involves mechanical rectification of the polygons with the aid of special software. The lines must first be traced from soils sheets, preferably from film positives rather than paper. (Film positives of soils sheets are available from USDA SCS, National Technical Center, Fort Worth, TX.) The traced lines must then either be digitized manually or electronically scanned. The soils map must include about 10 control points that represent identifiable points. The coordinates for these points may be taken from USGS 1:24,000 quads or an orthophotograph, or some other reliable large scale source.

Once the map information and control points have been digitized, they are processed by a program that adjusts the polygon lines to conform with the control points. This process, sometimes called "rubber sheeting," is not supported by GRASS, however. The user will probably need to contract the work to a firm that has the necessary software.

Although the corrected soils map lines more accurately conform to the actual ground locations they represent, the mechanical process that corrected them cannot always follow certain geographic features that usually delineate certain soil types. The transformed data should be examined by a soils expert, and inconsistencies between natural features (rivers, ridges, and coastlines, for example) and soil polygons should be noted. When the digital file is edited to reflect the judgments of the soils expert, the finished map layer may be converted to cell format and added to the GRASS database.

The GRASS user's other option is to manually adjust the inaccurate soil polygons. For this process, too, the developer needs film positives of the appropriate soils sheets containing the aerial photographs on which the polygons were drawn. It is also necessary to obtain (or have made) orthophotographs at the same scale as the soils sheets.

The orthophoto is laid over the film positive on a large light table. On top of these is placed a clean piece of mylar drafting film. Although the data developer may note that, for any one portion of the map, features such as roads and streams will fit accurately with the orthophoto, the soils map will exhibit an overall distortion. The data developer registers the orthophoto to the map so their features fit across a small portion of the soil map. The polygons on that portion of the map are redrawn onto the mylar. When this portion is complete, the orthophoto is reregistered at a different location and the appropriate soil polygons are traced. This process continues until the soil polygons across the entire map have been redrawn. This work should be carried out by a person with graphic skills and training in soil science.

Once the soils maps are redrawn, they are either manually digitized or electrically scanned. The new map layer is then ready to add to the GRASS database.

Each method has advantages and disadvantages. The mechanical method may be quicker, especially in cases where the data is complex or is already in digital form, and it may also be less expensive. The manual method, however, when properly executed, gives more dependable results. Decisions on the proper location of the polygon lines are made by a scientist rather than computer program. The manual method also provides the opportunity to improve and add to the soil data. If updating the content of the soil survey is important, the manual method is probably the preferable choice.

Introduction of Error Through Other Processes

As previously discussed, map data may be digitized manually or electronically scanned. Both methods can add some error to the final digital product.

In manual digitizing, an operator traces lines by hand, and defines coordinates to represent those lines digitally. Error introduced at this stage adds to that in the source material. Such error often arises from the tedious and fatiguing nature of manual digitizing. The operator should avoid digitizing for more than four hours a day to reduce fatigue-related error.

It is important for an operator to be fully trained to digitize before being entrusted with a project. The process is somewhat like drafting: a good eye and a steady hand are, as in drafting, valuable traits for the operator to possess. Nobody can digitize perfectly, but practice and knowledge about the process can significantly reduce errors. It has actually been observed that individuals tend to have an "error signature" that may be used as a tool to improve an operator's quality consciousness, thus reducing errors.[13]

[13] George F. Jenks, "Lines, Computers, and Human Frailties," *Annals of the Association of American Geographers*, Vol 7, No. 1 (March 1981), pp 6-7.

Checking the faithfulness of the digital product to its analog counterpart is best accomplished by plotting the digital map at the scale of the source, then laying the plotted map over the original. The plot must be done on a device of known reliability. This process allows both accuracy and completeness to be checked.

Electronically scanned map data is usually recorded as raster data of a very fine image resolution (at least 100 microns), which is then converted to the GRASS *digit* format. When done properly, the degree to which the digital data differs from the original lines is nearly indiscernible. One problem worth noting, however, may occur at sharp corners. The software used to process the scanned data may not be capable of placing a point exactly at the corner. The corner thus ends up being rounded in appearance. Scanned files must also be checked carefully for errors introduced because of mislabeled polygons, unsnapped nodes, or some misunderstanding by the operator about the job's requirements.

When digitized vector data is converted to cell format it must be processed by the GRASS program *vect.to.cell*. As mentioned previously, any vector-to-raster conversion will introduce error in the form of the jagged lines characteristic of raster data.

Another process that may introduce error is the tracing of map data from an original in preparation for either manual digitizing or scanning. Error is introduced at this stage whenever the person digitizing deviates from the line being traced. These errors can be kept to a minimum through training and practice, as well as by using a fine technical pen for the drafting.

Documentation

The final stage of making a GRASS cell file is to document it. In GRASS, the command *support* gives the data developer the opportunity to enter information about the cell file that will be helpful to the user, including information on the source map, its accuracy, the accuracy of the registration, special problems with the data, the digitizing threshold, the intended application for the data, and anything else that might help the user accurately assess the data. Without full documentation, the usefulness of data is greatly impaired. Appendix C gives a checklist for maintaining high standards in the construction of a digital database.

5 CONCLUSION

Important Technologies for Database Development

Throughout this report, an emphasis has been placed on the digitizing of data from existing maps, usually in printed form. But this is not the only way, or even the best way, to develop a GRASS database. When time and funding permit, map data can be collected from appropriate aerial photographs of the study area. Ground control surveys can be performed, and planimetric and terrain features may be collected photogrammetrically from the photography. This would avoid corrupting the data with the error already present in existing map sources, and overlays taken from the same photography would be consistent among themselves.

Although a photogrammetric method of collecting map data can reduce the load of in-house digitizing, this method is not without problems, too. For example, map developers using this method of data collection must consider the concept of digitizing threshold (as described in Chapter 3). The number of points used to depict a line must be adequate to depict that line smoothly on a plotter at the desired output scale. Additionally, such data must also be translated into GRASS *digit* format. Finally, when an outside firm handles the collection of map data, control of the results can be difficult. A person who knows nothing about the study area—tank trails on an Army installation, for example—cannot make an informed decision about which lines on the photographs actually depict tank trails.

Orthophotography, at a large enough scale to give adequate detail of the study area without excessive budget requirements, can be a valuable addition to a database. It can serve as a reliable base from which the GRASS user can recompile any information that needs to be added to a database. In this way, the orthophotograph can serve as the control that verifies accuracy among different map layers.

Scanning technology is improving to the point that scanned images may soon require less redrafting than they now do. Scanning of colored maps is also advancing. It may be more efficient in the future to remove unneeded features from a scanned map than to isolate the features of interest by redrafting on an overlay.

Some experimental work has been done in collecting map coordinate points directly from the ground by walking or driving along the path to be recorded. This technique involves the use of global positioning satellite technology, however, and questions about accuracy and cost must still be answered.

Importing Digital Data in Other Formats

In some cases it is most efficient to use existing digital data than to create it, so it is desirable to use such data when possible. The USGS, for example, can provide certain digital map data. Also, as the number of GIS and computer-aided drafting systems increases, more data will be created for these systems. Work is proceeding toward the conversion of data created for Intergraph workstations for use in a GRASS database. Translation between Digital Exchange Format (DXF) and GRASS formats is already possible.

Conclusion

GRASS software engineers are currently working on new programs involving the storage and collection of map data, and new cartography technologies are being explored. The problems of providing accurate maps in a timely manner will always exist, however. In order to make the best of what will always be a less-than-ideal situation, both the creators and the users of digital map data must be aware of the possibilities and limitations of digital cartographic technology.

REFERENCES

Agriculture Handbook 294, *Aerial-Photo Interpretation in Classifying and Mapping Soils* (U.S. Department of Agriculture Soil Conservation Service [USDA SCS], 1966), p 8.

Army Map Service (AMS) Training Aid No. 6, *Map Intelligence*, 2nd ed. (U.S. Army Corps of Engineers, 1954).

Bradshaw, Stuart, and Pam Thompson, *Options for Acquiring Elevation Data*, Technical Manuscript (TM) N-89/20 ADA220934 (U.S. Army Construction Engineering Research Laboratory [USACERL], January 1988).

Burrough, P.A., *Principles of Geographical Information Systems for Land Resources Assessment* (Clarendon Press, Oxford, 1986).

Field Manual 21-26, *Map Reading* (Headquarters, Department of the Army, March 1965).

Fleet, Harvey, Chief of Digital Cartography, U.S. Department of the Interior National Park Service (unpublished interview, 29 May 1990).

Glusic, Andrew M., *The Positional Accuracy of Maps*, AMS Technical Report 35 (Washington, D.C., 1961).

Goran, W., and R. Riggins, *Graphic Materials to Support Biophysical Quantitative Environmental Impact Analysis--Sources of Existing Materials*, Technical Report N-68/ADA069097 (USACERL, March 1979).

Jenks, George F., "Lines, Computers, and Human Frailties," *Annals of the Association of American Geographers*, Vol 71, No. 1 (March 1981).

Johnson, Mark, and William Goran, *Sources of Digital Spatial Data for Geographic Information Systems*, Technical Report N-88/B0466908 (USACERL, December 1987).

Martin, Mary V., William D. Goran, et al., *GRASS/GIS Implementation Guide*, Special Report N-90/02 ADA214623 (USACERL, October 1989).

Robinson, A., R. Sale, and J. Morrison, *Elements of Cartography*, 4th ed. (John Wiley and Sons, Inc., New York, 1978).

Shapiro, Michael, James Westervelt, et al., *GRASS 3.0 Programmer's Manual*, ADP Report N-89/14 (USACERL, September 1989).

Snyder, P., *Map Projections; A Working Manual*, USGS Professional Paper 1395 (U.S. Government Printing Office, Washington, D.C., 1987).

Thompson, Morris M., *Maps for America* (U.S. Geological Survey, 1979).

U.S. Army Corps of Engineers Army Map Service, map of Brunswick, GA (USGS, revised 1968).

Westervelt, James, Michael Shapiro, William Goran, et al., *GRASS User's Reference Manual*, ADP Report N-87/22 (USACERL, September 1988).

APPENDIX A:

DRAFTING MATERIALS

The following is a basic list of drafting supplies needed for techniques described in this report. (This list may vary among cartographers.)

Mylar (3.0 mil thickness)
Mylar is a thin plastic with a frosted matte finish on one side for drafting.

Technical drafting pens
Although technical pens are available in a wide range of line thicknesses, the weights 00, 0, and 1 are sufficient to prepare maps for manual digitizing and scanning.

Pen cleaner
Technical pens clog when ink dries in their tips. This cleaner is a [illegible] solvent that dissolves clogs.

Waterproof black ink
Waterproof ink adheres to mylar better than does water-soluble ink, but it can be removed from mylar with a dampened eraser.

Nonphotographic blue pencils
These are useful because their imprint is invisible to photography and scanning. They may be used to draw guides for ink lines without worry that they will be recorded unintentionally.

Triangles (with raised edges)
These are for drafting short straight lines. Raised edges prevent ink from smearing underneath the triangle during drafting. Drafting triangles come in two types: the 30-60-90 type and the 45-45-90 type. Triangles of varying sizes are useful.

T-square
This is used with a triangle to produce a perfect 90-degree angle to an established line. It is also useful as a long straightedge.

Long metal straightedge
A metal straightedge is useful for making straight cuts in mylar and acetate. Plastic ones should not be used as cutting guides because they are easily gouged.

French curve
This is a curved plastic tool that is invaluable for drafting a variety of curves. A variety of sizes is useful.

Templates
Templates are guides for drafting standard geometric features, such as squares, triangles, circles, and ellipses. A template usually features a shape in several different sizes.

Ruler
Rulers should be finely calibrated so precise measurements can be made.

Ink eraser (for plastic)

These erasers are designed especially to remove ink. Pressing too hard during erasure may damage the coating on mylar, however.

Kneaded eraser

These don't shed bits of rubber like standard pink pencil erasers. They work well to remove fingerprints from the drafting film.

Eraser shield

This is usually a flat piece of metal with different small shapes cut out of it, used to erase a small portion of a line. The shield protects the portion of the line not needing correction.

Mineral spirits (or alcohol)

These liquids, used to clean drafting film, remove skin oils from mylar and evaporate almost immediately. Do not randomly wipe the mylar; either wipe up and down, or from side to side. Excessive pressure during cleaning may remove the mylar's coating. Skin oil prevents ink from adhering to the mylar properly. Once the mylar is clean, only handle it by its edges. Shield the mylar from hand smudges with a piece of paper.

Razor or knife

Use a single-edged blade or a razor knife with replaceable blades, such as an X-acto® knife. It may be used to cut mylar or paper, and to touch up small inked lines. Use caution because blades can easily damage mylar. Large lines should be edited with an ink eraser.

Drafting brush

Used for brushing foreign debris from the mylar. It helps prevent marring the surface with skin oils.

Drafting tape

This special tape is not as sticky as masking tape, and is easily removed from paper or mylar without causing damage.

Clean rags

Use them for cleaning mylar and pens.

APPENDIX E:

CONVERSION FACTORS FOR REPRESENTATIVE FRACTIONS (MAP SCALES)

	Ratio Scale	Feet per inch	Inches per 1000 feet	Inches per mile	Miles per inch	Meters per inch
1:	500	41.667	24.000	126.720	0.008	12.700
1:	600	50.000	20.000	105.600	0.009	15.240
1:	1,000	83.333	12.000	63.360	0.016	25.400
1:	1,200	100.000	10.000	52.800	0.019	30.480
1:	1,500	125.000	8.000	42.240	0.024	38.100
1:	2,000	166.667	6.000	31.680	0.032	50.800
1:	2,400	200.000	5.000	26.400	0.038	60.960
1:	2,500	208.333	4.800	25.344	0.039	63.500
1:	3,000	250.000	4.000	21.120	0.047	76.200
1:	3,600	300.000	3.333	17.600	0.057	91.440
1:	4,000	333.333	3.000	15.840	0.063	101.600
1:	4,800	400.000	2.500	13.200	0.076	121.920
1:	5,000	416.667	2.400	12.672	0.079	127.000
1:	6,000	500.000	2.000	10.560	0.095	152.400
1:	7,000	583.333	1.714	9.051	0.110	177.800
1:	7,200	600.000	1.667	8.800	0.114	182.880
1:	7,920	660.000	1.515	8.000	0.125	201.168
1:	8,000	666.667	1.500	7.920	0.126	203.200
1:	8,400	700.000	1.429	7.543	0.133	213.360
1:	9,000	750.000	1.333	7.041	0.142	228.600
1:	9,600	800.000	1.250	6.600	0.152	243.840
1:	10,000	833.333	1.200	6.336	0.158	254.000
1:	10,800	900.000	1.111	5.867	0.170	274.320
1:	12,000	1,000.000	1.000	5.280	0.189	304.801
1:	13,200	1,100.000	0.909	4.800	0.208	335.281
1:	14,400	1,200.000	0.833	4.400	0.227	365.761
1:	15,000	1,250.000	0.800	4.224	0.237	381.001
1:	15,600	1,300.000	0.769	4.062	0.246	396.241
1:	15,840	1,320.000	0.758	4.000	0.250	402.337
1:	16,000	1,333.333	0.750	3.960	0.253	406.400
1:	16,800	1,400.000	0.714	3.771	0.265	426.721
1:	18,000	1,500.000	0.667	3.520	0.284	457.201
1:	19,200	1,600.000	0.625	3.300	0.303	487.681
1:	20,000	1,666.667	0.600	3.168	0.316	508.002
1:	20,400	1,700.000	0.588	3.106	0.322	518.161
1:	21,120	1,760.000	0.568	3.000	0.333	536.449
1:	21,600	1,800.000	0.556	2.933	0.341	548.641
1:	22,800	1,900.000	0.526	2.779	0.360	579.121
1:	24,000	2,000.000	0.500	2.640	0.379	609.601
1:	25,000	2,083.333	0.480	2.534	0.395	635.001
1:	31,680	2,640.000	0.379	2.000	0.500	804.674
1:	48,000	4,000.000	0.250	1.320	0.758	1,219.202
1:	62,500	5,208.333	0.192	1.014	0.986	1,587.503
1:	63,360	5,280.000	0.189	1.000	1.000	1,609.347
1:	96,000	8,000.000	0.125	0.660	1.515	2,438.405
1:	125,000	10,416.667	0.096	0.507	1.973	3,175.006
1:	126,720	10,560.000	0.095	0.500	2.000	3,218.694
1:	250,000	20,833.333	0.048	0.253	3.946	6,350.012
1:	253,400	21,120.000	0.047	0.250	4.000	6,437.389
1:	500,000	41,666.667	0.024	0.127	7.891	12,700.025
1:	1,000,000	83,333.333	0.012	0.063	15.783	25,400.050

Source: Agriculture Handbook 294, *Aerial-Photo Interpretation in Classifying and Mapping Soils* (USDA SCS, 1966), p 80.

APPENDIX C:

A CHECKLIST FOR MAINTAINING A HIGH STANDARD FOR DATA DEVELOPMENT

1. Do not assume that source data is accurate. Check out and document its usefulness. Remember that the final digital map will never be more accurate than the source.

2. Obtain map information on plastic separates whenever possible.

3. Work with map data before entering it into a database to ensure that it is as accurate as possible, and that it will line up as accurately as possible with related overlays.

4. Recompile map data, when necessary and feasible, using either manual or computer-aided processes.

5. Do not underestimate the potential for creating new error when manually digitizing. Make certain that people doing the digitizing are trained for the job before undertaking a project. Don't expect anyone to digitize more than 4 hours per day.

6. Print a proof on a plotter to check the accuracy and completeness of digitized data against analog sources.

7. Provide complete documentation for each map layer to help the user assess the usefulness of the data for a given project.

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